AN EXPERIMENTAL STUDY OF THE MOVEMENTS OF HERRING AND OTHER MARINE FISHES.[1]

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I. Introduction.

The general problem of increasing the supply of any species of fish or any other aquatic food animal, or of maintaining such species against extensive catch and against pollution of waters with sewage and the waste products of manufacturies, is very complex. The older methods of study are as important now as ever. The study of the food of an animal, its relation to its natural enemies, and its breeding habits still must receive their proper share of attention. In addition to these we now know that attention must be given to the chemical condition of the water, its effect on the movements and migrations and general health of the animals. Likewise it is especially important to study the physical and chemical conditions in which the animals breed and to look especially into the matter of the *preservation of the natural breeding grounds*. It is well known that one of the reasons for the depletion of the white-fishes in Lake Michigan is the destruction of their breeding grounds by the addition of sewage, saw-dust and other refuse to the water, which has settled on the breeding grounds and rendered them uninhabitable

[1] Contribution from the Puget Sound Marine Station.

by the lowering of the oxygen content and covering the surface with materials which bury and tend to smother the eggs during development. The number of individuals of a species is never any greater than the breeding grounds can support. Finley ('13) has shown that the number of prairie chickens in certain counties of Illinois is directly proportional to the area of breeding grounds. Likewise the senior author (Shelford, '11) has shown that in a series of ponds at the head of Lake Michigan, food fishes are absent where their food is *greatest in quantity* because the breeding conditions are absent, due to the covering of the bottom with the decaying food of fishes. It is especially noteworthy that the food of the youngest fishes is especially abundant in ponds where the best food fishes cannot breed. This is not due to the failure of young fishes to destroy the small crustacea, because the same principle holds for ponds in which there are as many crustacea-eating fishes in stages suitable for *food* fishes as in stages suitable for only non-food fishes.

The economic justification for the study of the movements of fishes is two fold. First experimental studies are concerned with the question of the conditions which the fishes select or reject when presented with two or three kinds of water to which they have free access under experimental conditions. Their importance in this connection is based upon the fact that so long as we are concerned with conditions which the fishes habitually encounter in nature, the selections or rejections represent in a general way the physiological character of the fishes and as a rule conditions which fishes reject are detrimental if continued for a long time. Thus, as we shall see later, fishes turn away from water containing hydrogen sulfide and we will show further that they die very quickly when exposed to only a small excess of this gas in the sea water. Here then the fish is so constituted that its behavior and safety are intimately linked. Of course there are exceptions to this rule and it does not hold when we are concerned with changes in conditions which are not commonly encountered in nature. Thus we learn something of the conditions that are probably deleterious to the animals without either killing them or breeding them continuously under the modified conditions. The second justification lies in the fact that we can learn by

such experiments the effect of advancing civilization and industry upon the presence or absence of a species in any locality. The movements of the fishes must be known as well as the cause therefor, before we can intelligently approach the question of capturing them in quantities.

II. Material and Methods.

1. *Stock of Fishes.*

The material used in these experiments was chiefly the fry of the herring (*Clupea pallasii* Cuvier) 6 cm. (2½ in.) common in Puget sound. The fry were caught on July 2 and were kept in a float car anchored in a good tide and until July 22 practically none of the fish died except during the first few days when those probably injured in catching were the chief victims. A few soles (*Lepidopsetta bilineata* Ayres) secured on July 4 at Fisherman's bay, Lopez Island, were kept in the same car. A few young humpback salmon (*Oncorhynchus gorbuscha* Wal.) 7 cm. (2¾ in.) long were secured at sea, through the courtesy of Dr. E. Victor Smith on June 30, at Turn Island and were not used after July 8 as they did not appear to be in normal condition after that date. A single Cottid (*Oligocottus maculosus* Girard) was used in killing experiments. The soles and herring appeared to be in essentially as good condition at the end of the period of work as at the beginning.

2. *The Water Supply of the Station.*

Experiments were run in which both fresh and salt water were used. Thus it is necessary to consider the character of both. The fresh water in use during the summer of 1914 was supplied by the village of Friday Harbor and came from deep wells. Owing to the rocky character of the ground in the vicinity, it was impracticable to bury the pipes and the temperature varied greatly with the weather, night, day, etc. The highest temperature noted was 24° C. The water contained an excess of gas which escaped in a cloud of bubbles when it was withdrawn from the tap. This was neither oxygen nor carbon dioxide and gave no odor which points to the conclusion that it was nitrogen. The water was distinctly alkaline to phenolphthalein, free carbon

dioxide being wanting. The half bound carbon dioxide was 24.2 c.c. per liter and the fixed 28.6 c.c. The oxygen was less than 0.5 c.c. per liter (for methods see Birge and Juday, '11, pp. 13–21). Such water is unsuitable for biological purposes and was used in these experiments only after aëration by running it slowly over an inclined board ten inches wide and four feet long. After this aëration the oxygen content was, at 13° C., 4.9 c.c. per liter and the excess of other gas was removed, but the water still remained alkaline.

The sea water supplied at the station building was pumped from a depth of about four feet below mean tide. It was retained in a wooden tank, being pumped twice per day, in the evening and in the morning. Upon standing in the tank the temperature rose from 11° to nearly 15° on warm days.

The oxygen was determined by the Winkler method. In no case was the sea water from the tank or from the bay from which it was pumped, saturated with oxygen even in samples collected at the surface. The only surface collection made that showed saturation according to the tables of Fox (see Murray and Hjort, '12, p. 254) was from the strong tide rips off Point Caution at 5:30 P.M. Collections from the bottom of sandy shores among *Ulva* were super-saturated.

Chlorine was determined by titrating with silver nitrate. It usually amounted to about 16.93 grams per liter. It was usually a little higher in water from the tank than in water collected from the sea. The determination of carbon dioxide was made by the method in common use in fresh water. The sea water was titrated with $\frac{1}{20}$ normal solution of sodium carbonate, with phenolphthalein as an indicator. The water was usually acid in reaction indicating about 1.7 c.c. per liter of free carbon dioxide. The half bound and bound carbon dioxide as indicated by the method used by Birge usually amounted to 25.3 c.c. per liter each. There was considerable uniformity in the results of such titrations and while the method is not especially accurate the lack of oxygen common in the water would indicate an excess of free carbon dioxide over that commonly reported for sea water. The correctness of these figures is further suggested by the slight alkalinity of the water taken from the vicinity of green algæ and containing an excess of oxygen.

Hydrogen sulfide is very commonly present in sea water when decomposition is taking place. This was determined by titration with iodine which was the only method we were equipped to employ. It is never present in any quantity in freely circulating waters. The highest records are for collections made near the bottom under *Ulva*, where the odor is often quite distinct. On account of the probable presence of other substances which may absorb iodine the determinations may be slightly too large (Birge and Juday, '11).

TABLE I.

THE DISSOLVED GASES OF THE SEA WATER ABOUT FRIDAY HARBOR, WASHINGTON. DATA IN C.C. PER LITER.

Date.	Place.	Hour.	Tide.	Collected.	CO_2.	O_2.	H_2S.	Temp.
	Point Caution	5:30 P.M.	Low, in	Surface		5.6		
7/23	N. E. Brown's Id.	10:10 A.M.	Low, out	Surface	1.76	4.9	.187	11.6
7/25	Do.	11:10 A.M.	Low, out	Surface	1.64	4.6	.237	10.7
7/25	Do.	7:15 P.M.	High,	Surface	1.91	4.6	.268	10.5
7/26	S. Brown's Id.	10:45 A.M.	Low, in	8″ under *Ulva*	0.00	9.2	.536	16.5
7/23	Do.	12:00 M.	Low, in	Do.	0.00	10.8	.536	13.2
7/25	Do.	12:00 M.	Low, in	18″ Do.	0.00	—	.339	13.2
7/25	Station dock	11:10 A.M.	Low, in	Surface	1.86	5.2	.149	11.6
7/25	Do.	12:45 P.M.	Low, in	Surface	3.10	4.8	.205	
7/26	Do.	9:30 A.M.	High, out	Do.	1.81	4.2	.295	10.6
7/26	Tap-pumped at	6:30 A.M.	Med. low	4′ deep	1.76	4.7	.223	

It will be noted from a study of the table that the water from Point Caution where the tide has full sweep is the only water saturated with oxygen at the surface. In other places the sea water at the surface is about 1 c.c. less than the amount given by Fox (see Murray and Hjort, '12, p. 254). Aërating the sea water increased the oxygen. The water from the tank did not seem to have been modified by standing for sixteen hours or more. On the whole there must be much decomposition in Puget Sound waters. There was no constant difference between the water from outside and inside the side of the island which encloses Friday Harbor. The CO_2 is a little higher except at low tide in the sample taken near the *Ulva;* the oxygen remains about the same. The hydrogen sulfide does not average appreciably higher.

The explanation for the alkaline character of the water under the *Ulva* is that the plants take up the CO_2 and give off oxygen and thus remove the excess which occurs in other localities.

The absorption of oxygen in connection with the development of the hydrogen sulfide probably prevents any very great excess of CO_2 from accumulating (Lederer '12).

III. The Resistance of Fishes to Contamination and Decomposition Products.

It was not possible to try the resistance of the fishes (Wells, '13) to the effect of the lack of oxygen either separately or in combination because no means of removing it was at hand. It was possible only to add gases to the water. Hydrogen sulfide and carbon dioxide were used.

1. *Herring* (*Clupea pallasii Cuvier*).

Hydrogen sulfide is extremely poisonous to the fishes (Weigelt, '03). In the first attempted gradient experiments where the water at one end contained only a little of the gas the fishes turned on their backs in two or three minutes when the one inflow was showing 8.3 c.c. per liter and the other was pure sea water. This happened in spite of the fact that more than half of the time was spent in the end with least H_2S. The experiments were performed in the manner described by Wells. When placed in a solution of 7.6 c.c. per l. the herring gasped *after 1 minute and 45 seconds*, turned over after 5 minutes, and were apparently all dead in 6 minutes. In carbon dioxide of about 20 c.c. per l. the herring showed evidence of loss of equilibrium after three minutes. Some of them sank to the bottom after 12 minutes. After 39 minutes to 62 minutes herrings turned on their sides on the bottom, resting in this position for a time and then swimming more nearly normal for a time again. One died after 102 minutes, the others after 159 minutes' exposure. The oxygen was about 5.5 c.c. per l. and varied directly with the amount of tank CO_2 used, indicating that the carbon dioxide contained much oxygen.

When carbon dioxide and hydrogen sulfide were used together the carbon dioxide was about 30 c.c. per l. and the hydrogen sulfide 2.9 c.c. per l. The amounts were controlled with some difficulty and thus the experiments are not alike in the matter of concentration. Herring were much stimulated at the beginning.

After 1 minute and 30 seconds there was a general loss of correlation of movements. At the end of four minutes all the herring were dead. Thus we note that the combination of hydrogen sulfide and carbon dioxide is exceedingly deadly. In alkaline partly aërated fresh water herring showed loss of equilibrium in from 10 to 14 minutes. They nearly succumbed and then recovered a few times, the first one dying after 30 minutes and all being dead in 44 minutes.

2. Soles (*Lepidopsetta bilineata Ayres*).

In the hydrogen sulfide (7.6 c.c. per l.) the soles showed some signs of loss of equilibrium at the end of one minute. In 5 minutes they were on their backs. After 13 minutes they had revived again. They were nearly dead after 16 minutes and all dead at the end of 24 minutes.

In the carbon dioxide (20 c.c. per l.), after 45 minutes one sole gasped, which was the first sign of any disturbance and one turned on its back after 54 minutes. For three hours this was repeated at intervals and each gasping time was followed by recovery.

In the combined carbon dioxide (30 c.c. per l.) and hydrogen sulfide (2.9 c.c. per l.) the soles lost equilibrium after 2 minutes and 30 seconds. In 11 minutes they were barely alive and in 13 minutes were dead. In fresh water the soles showed stimulation at the end of 3 minutes. They died in from 48 minutes to one hour.

3. Cottid (*Oligocottus maculosus Girard*).

One fish of this species was added from curiosity but the results were sufficiently surprising to record. In the hydrogen sulfide the cottid seemed unaffected until the end of 6 minutes, after the herring were all dead. It breathed heavily after 16 minutes. The fish was alive at the end of three hours when it was returned to running salt water, and allowed to recover, after which it was used in the carbon dioxide experiment, with similar results. In the combined carbon dioxide and hydrogen sulfide it was not visibly affected and in fresh water there was no evidence of any disturbance. These fishes were seined from the sandy bottom among the *Ulva*, coming in with numbers of the small soles.

4. *Summary.*

We note that on the whole the presence of a quantity of carbon dioxide in the water affected the fishes less than a smaller amount of hydrogen sulfide. The combination of hydrogen sulfide and carbon dioxide was most rapidly fatal. Since decomposition yields CO_2 and consumes oxygen and is accompanied by the production of hydrogen sulfide which is also accompanied by the consumption of oxygen, it is reasonable to suppose that on a bottom from which vegetation is absent and decomposition actively takes place a fatal combination of lack of oxygen, and presence of hydrogen sulfide and probably carbon dioxide can develop quickly.

Considering the fishes tested we note that the herrings were most sensitive. They were sharply marked off from the bottom species which are resistant to a marked degree. This resistance is in a very general way associated with the habitat preference of the species. Still the marked resistance of the small cottid is not quite explicable on this or any other basis.

The importance of factors which kill fishes is greatest in the early stages for two reasons. First the small size of the eggs and embryos makes the ratio between volume and surface smallest and thus any substance in solution will reach all parts of the organism at a more rapid rate. Secondly the inability of the eggs and embryos to move about makes them the easy victims of any adverse conditions that may occur. The eggs of the herring are deposited on the bottom. Nelson mentions rocks only (Marsh and Cobb, '10, p. 46) and rocks are usually swept fairly clear of organic matter and the water well aërated down to the depth of one fathom where the fishes breed. If this means that sandy bottoms of bays are avoided it probably means the avoidance, during the breeding, of water high in hydrogen sulfide (see table) which would be fatal to the eggs and small herring fry to a greater degree than to those studied, which were 6 cm. long. Sensitiveness to hydrogen sulfide is a matter of much importance from the standpoint of the suitability of a given arm of the sea for herring and the influence upon fishes of contamination of the shores with refuse from the land.

Carbon dioxide is not high in such shallow water on account

of the presence of so many green plants. Carbon dioxide is probably more important in connection with movements of the fishes than in the matter of restricting their breeding places.

IV. Reactions of Fishes to Chemical Conditions in Sea-Water.

1. *Conditions and Methods of Study.*

The experiments were performed in a gradient tank. Water of two kinds was used in the experiments. One kind was allowed to flow into one end at a definite rate and another kind into the other end at the same rate. It flowed out at the middle at the top and at the bottom so that the two kinds of water met at the center. The outflow at the center did not of course prevent the mixing of the two kinds of water and thus the middle section, equal to one half or one third of the tank was a gradient between the two kinds of water. The tank used in these experiments was 122.3 cm. by 15 cm. by 13 cm. deep. The front wall was of plate glass and a plate glass top was used at times. Water was allowed to flow in at both ends at the same rate (usually 600 c.c. per minute) through tees the cross bars of which contained a number of small holes. The cross bars of the tees were at the center of the ends of the tank behind screens. The drain openings were located at the center near the top and in the bottom. The outer openings of the drain tubes were at the level of the water in the tank. The water flowed in at the ends and drifted toward the center and flowed out through the drains. We found no evidence that fishes react to the slight current thus produced. Since each half of the tank held about 9 liters, it required 15 minutes to fill it or to replace all the water in one of the halves. The tank was enclosed under a black hood. Two candles (electric lights being wanting) were fixed in the rear and above the center of the two halves, *i. e.*, above a point midway between the screen partition and the center drain. The light was 15–20 cm. above the surface of the water which was 13 cm. deep. The room was darkened during the experiments which were observed through openings in the hood above the lights or through the glass side late at night. Fishes do not usually note objects separated from them by a light.

Water differing as little as possible from that in which the fishes usually live was used for control readings. Controls were observed and the conditions in the two ends of these were the same either because the water introduced at the two ends was alike or because no water was run into either end (standing water).

In the controls the fishes usually swam from end to end in a rather symmetrical fashion, and thus by comparing these movements with those occurring when the fishes encountered differences in water, we are able to determine the reactions of the fishes to the differences. Various kinds of water were used at one end as follows: (1) water with varying amounts of carbon dioxide added; (2) water with oxygen added; (3) water with hydrogen sulfide added; (4) fresh water.

When the difference between the solutes at the two ends of the tank was not great we found by chemical tests that the central portion of the tank was a gradient between the characteristic waters introduced at the two ends. Usually the end thirds were essentially like the inflowing water. When the difference in concentration was great the region of the gradient was proportionally longer and the ends with the inflowing concentrations correspondingly shorter. When the difference in concentration was very great the entire tank was gradient. For an experiment a fish was placed in a dish containing enough water to barely cover it and set above the tank. When all was in readiness the fish was emptied into the center of the tank. Marks on the sides divided the tank into thirds. The fish nearly always swam back and forth, apparently exploring the tank. The movements of the fish were recorded graphically as shown in Chart I. For this purpose sheets of ruled paper were used. Four vertical double rulings corresponded to the thirds and two ends of the tank. Distance from right to left was taken to represent the length of the tank, vertical distance to represent time and the graphs drawn to scale. The width of the tank was ignored. The graphs on the following pages are copies of the originals.

Before or after the experiment, the headings of the sheets were filled with data regarding the kind, size, and previous history of the fish, the conditions in the tank, concentration of

the solutes and other significant data. The fish was observed continuously for twenty or more minutes.

In order to maintain a constant flow the water was introduced into the tank by means of siphons from cans on the top of the hood with a 74 cm. head. Connected with one of the two cans was an inclined plank trough 420 cm. by 25 cm. for the purpose of aërating water before it entered the can if so desired.

By the method just described it is possible to obtain unusually accurate data on the factors influencing the movements of fishes. According to Marsh and Cobb ('07) a great difficulty in the herring fishery is the erratic movements of the fish. Schools may visit a bay for three or four years, in succession, and then without any apparent reason, avoid it for a season or two or altogether. Bertham ('97) noted a possible relation between the abundance of these fishes and weather and suggests that climatic cause may have more to do with the failure of some branches of the fisheries than is generally believed. He attributed the failure of the fisheries of Cape Benton to the occurrence of severe east and northeast storms during the running season. It is not clear what the effect of such storms may be, but they chiefly affect the dissolved content of the water. Johnstone, '08, page 246, says that it is now nearly certain that the shoaling migrations of the herring of Europe are to be associated with the salinity and temperature of the sea. It is evident from these experiments that acidity and alkalinity are more important than salinity and the solution of the problem will come from a careful study of the reactions of fishes along with a similar study of hydrographic conditions.

2. *Reactions to Temperature.*

These fishes are remarkably sensitive to differences in temperature. We obtained good reactions with a difference of 0.6° C. in the length of the tank. Fair reactions were obtained with differences of 0.5° C. and since the fishes often turned around near the center it appears that they recognized a difference of 0.2° C. In graph 1, Chart I., we show the reaction of fish in a gradient of 0.6° C. (compare with graph 2—control). The fish was taken from sea water at 10.9° and the experiment performed

at 12.8° and 13.2°. It will be noted that the fish showed a preference for the higher temperature. Eleven experiments were performed with herring and in seven cases the fishes showed a preference for the warmer water and in three cases for the colder. One did not show any marked preference. The differences were too slight to be of great significance in determining whether the fishes move into warmer or colder water but show a great sensitiveness. Thus temperature may play an important rôle in the movements of fishes.

It will be noted by reference to the graph, that the fish moved into the colder water several times as if trying out the entire tank and then turned back periodically from the colder end. In the control where there was no flow or difference in temperature the fish turned back from both ends at times but by chance as shown by other controls, turned a little more often from the end corresponding to the cold end of the experiment due perhaps to difference.

3. *Hydrogen Sulfide.*

The animals turned back sharply from all concentrations not great enough to cause intoxication as shown in graph 3, Chart I. (compare with control graph 4). In this experiment the hydrogen sulfide was only 4.5 c.c. per l. and the fishes avoided it sharply and after trying out the tank turned about at a point where the concentration could not be more than one tenth of that at the treated water end or about equal to that under the *Ulva* on the south side of Brown's Island (p. 319).

This experiment is typical of several and the fishes are thus seen to be able to orient with reference to an increase in the solute and to turn back from it very sharply.

The control (graph 4) to this experiment is symmetrical, there being turning from both ends in equal number. It shows the reaction of the fishes when no stimuli are encountered in the tank.

4. *Reactions to Salinity, Acidity and Alkalinity.*

As noted above, the fresh water of the laboratory was from deep wells and not good for biological work. It was alkaline, containing no free carbon dioxide, 24.2 c.c. per l. half bound and

28.6 c.c. per l. of bound carbon dioxide. There was a deficiency of oxygen and what was present was probably due to leaky pipes. It was only 0.5 c.c. per liter. It contained a large excess of some odorless gas which escaped in bubbles and was probably nitrogen. This water was aërated by running it over a board 420 cm. long, into the siphon bucket. This reduced the gas in excess to air saturation and raised the oxygen to 4.8 c.c. per liter.

In the experimental tank the difference between the density of the fresh and salt water was so great that the fresh extended nearly to the opposite end at the top with very little mixing and the salt water occupied a corresponding place on the bottom. Thus there was a sharp gradient from top to bottom, but a very imperfect one from end to end. To avoid this siphons were inserted which withdrew water from each side near the bottom at a point one third the length from the salt end and from near the top at the same distance from the fresh end. This was found not to remedy the difficulty sufficiently and so a screen incline which extended from bottom at the salt end to the height of 8.5 cm. at the fresh end. Above this was another screen which was 8.5 cm. at the salt end, and which ran up to the surface of the water at the fresh end. This enclosed the fish in an inclined cage 8.5 cm. deep at the salt water end and 5.0 cm. deep at the fresh end. The fish moved back and forth in this at a distance of about 4 cm. from the lower screen. The gradient of salinity between the acid sea water and the alkaline fresh water was essentially as perfect as shown in the accompanying Fig. 1. By

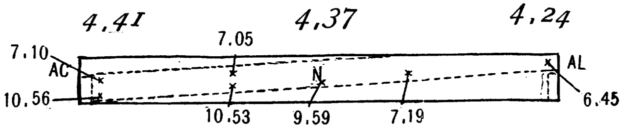

FIG. 1.

FIG. 1. Showing the distribution of salinity in terms of grams of chlorine per l. in Roman and oxygen content in c.c. per l. in italics; Al, alkaline; N, neutral; Ac, acid.

consulting this figure it will be seen that the oxygen content was essentially the same throughout. The salinity corresponded to 10.561 grams of chlorine in the salt water end to 6.45 grams in the fresh water end. The acidity to phenolphthalein reached

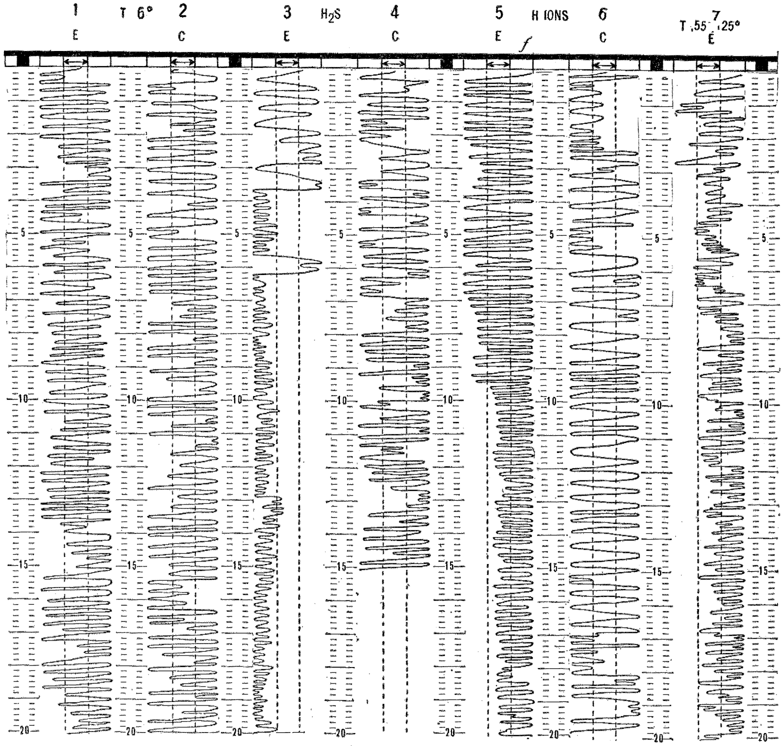

CHART I.

E, experiment; *C*, control; *f*, fresh water, *T*, and figures following show temperature difference.

Graph 1 shows the reaction to a difference of 0.6 of a degree the lower avoided temperature being on the left. Graph 2 shows the movement of the fishes in the tank when there is no difference in temperature (see also graph 6 and other graphs marked *C*).

Graph 3 shows the avoidance of hydrogen sulfide introduced at the right. After a few trials the avoidance became very sharp. Graph 4 is the control, *i. e.*, with no difference between the ends.

Graph 5 shows the reaction of a fish to fresh water introduced at the right showing the avoidance of the acid salt water and selection of the alkaline fresh water with the incline described on p. 327 in position. Temperature the same at the two ends. Graph 6 is the control of the same.

Graph 7 shows the selection of lower temperature with the incline screen cage in position; difference in beginning .55° C., at end .25° C. A difference in temperature occurred in some of the incline experiments but lower at the salt end. The graph shows that the fishes would have selected the salt water end where the temperature was a little lower if they had been reacting to temperature.

almost to the center while the central region was essentially neutral. Consulting graph 5, Chart I., we note that the fish moved the entire length of the tank for two minutes and then began to turn back before the highest salinity was reached. After a few such turnings it went the entire length of the tank for a short period with one exception. Between the 7th and 14th minutes the excursions into the salt water were gradually shortened. In other words after a few brief entrances into the salt water the fish gradually shortened its invasions of the salt water until it was turning rather regularly just on the alkaline side of neutrality, which continued to the end of the observation. It will also be noted that the fish turned back twice from the fresh water end, which is significant because in other cases the fishes selected this region. This was true in four other experiments with the incline and in six out of eleven performed without the incline. It appears that the herring select either brackish or slightly alkaline water. The control, graph 6, is symmetrical.

In some of the experiments performed with the incline there was a slight difference in temperature between the two ends, the fresh water being a little higher. To check this source of error, the experiment was performed with the incline but with the difference in temperature reversed, and the fishes selected the opposite end of the tank, showing that this was not only a reaction to solutes but that the solutes inhibited any reaction to temperature that might otherwise have taken place (graph 7). In the temperature experiments the fishes selected the higher temperature when the stock was fresh and the lower temperature near the close of the work showing that the fishes had undergone some slight physiological change during their stay in the float-tank.

The tendency to come to rest in the region on the alkaline side of neutrality was very clearly shown in all the experiments except one. The salmon oriented with their heads toward the fresh water end, drifting very slowly back, probably floating in a current and then swimming up again to the same point. This was very striking and constituted an unmistakable difference between the experiment and control. Chart II., graph 13 and 14, show such an experiment and control. The swimming up occurred notably in the 13th and 18th minutes.

To determine whether or not this peculiarity is a reaction to salinity or alkalinity, the experiment with herring was repeated and carbon dioxide to which the fish are negative (graphs 8 and 9) run in the fresh water, to neutralize the alkalinity. At the beginning of the experiment shown in Chart II., graphs 10 and 11, the carbon dioxide content of the fresh water was 26.5 c.c.

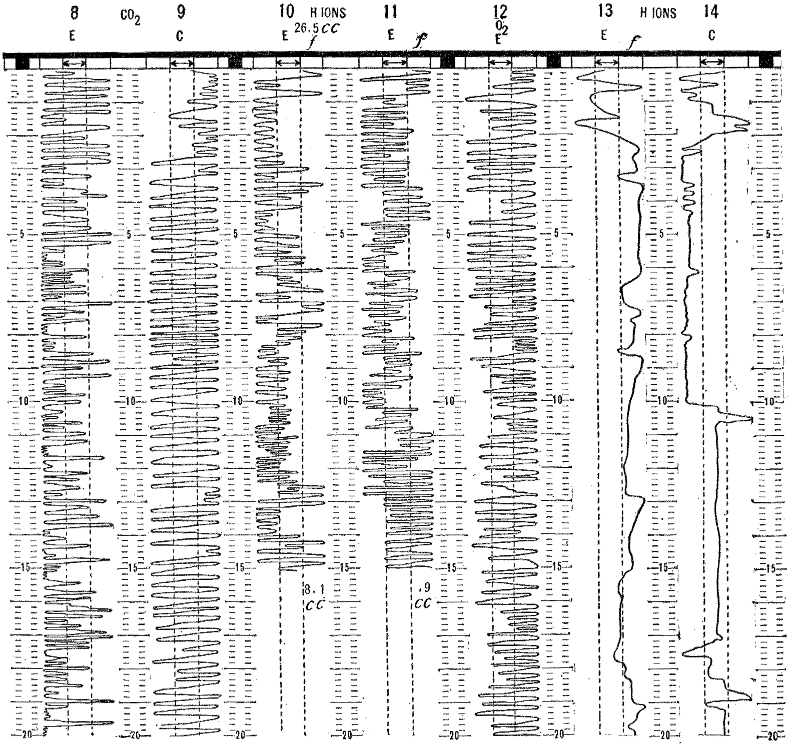

CHART II.

Graph 8 shows the avoidance of carbon dioxide in sea water introduced at the right. Graph 9 is the control of the same.

Graphs 10 and 11 show the reaction to fresh water rendered acid by the addition of 26.5 c.c. per liter of carbon dioxide and the reversal of the reaction when the carbon dioxide fell to 8.1 c.c. and finally the gradual reversal to a preference for the fresh water when it became less acid than the salt.

Graph 12 shows the preference for sea water with oxygen added (right end.)

Graph 13 shows the selection of essential neutrality by a small salmon. 14 is the control of the same.

per l. and the reaction was very sharply negative to fresh water. The concentration of the carbon dioxide in the fresh water was gradually lowered and the avoidance fell off as is shown in graph 12 which was really only a continuation of 11 interrupted to take a sample which showed the carbon dioxide content to be 8.1 c.c. per l. During the period represented by 11 the negative reaction decreased gradually until a point was reached when the tank was probably about equally acid throughout, after which the fish became negative to the sea water at the end of 13 minutes when on the basis of a uniform decrease the sea water which usually contained a little less than 2 c.c. per l., became more acid than the fresh. Thus it appears that these fish are as sensitive to acidity as litmus paper.

The relation of the two species of fishes to salinity is interesting in this connection. The salmon goes into fresh water to breed and some may reach maturity there or they may return to salt at varying ages. In connection with the entrance of salmon into fresh water, the orientation of these specimens with head in the fresh water is of interest but it is evident that the orientation is with reference to acidity and alkalinity rather than salinity. Sea water is less acid than fresh and the reactions of the salmon accord with their recent entrance into salt water. In the case of the herring, they are known to enter fresh water and some remain there permanently. Lydekker[1] states that some of them will live in brackish water and become dwarfed.

When carbon dioxide was used in sea water the avoidance of the higher concentration was very striking, in all concentrations tried, up to 70 c.c. per l. The avoidance was usually proportional to the concentration with staggering in the very high ones just as is the case with the fresh water fishes.

6. *Oxygen.*

The oxygen in the sea water in use at the station never reached saturation. One experiment was tried with water drawn directly from the tap, against water aërated by running over a board. The fishes selected the aërated water. When oxygen was added to the water used in opposition to that drawn directly

[1] *New N. H.*, Vol. V., p. 489.

from the tank the preference for the higher oxygen content was decided (graph 12).

V. Summary and Discussion of Conclusions.

In these brief experiments we have only outlined the possibilities of much more extensive work along similar lines. Such experimental study alone can of course not solve the problems of migration but the extreme sensitiveness of the fishes studied, as shown by their detection of slight deviations from neutrality, temperature differences as small as 0.2 of a centigrade degree, of small fractions of a cubic centimeter per liter of hydrogen sulfide, etc., makes it very clear that there is no difficulty in fishes determining the direction to large rivers from hundreds of miles out at sea or of finding their way into any bay or harbor or river or other arm of the sea which their particular physiological condition at a given time demands. It is not necessary to appeal to "instinct" to explain the return of certain salmon to certain rivers, or the running of herring in certain localities. The mere fact of their origin in the region, the probable limited tendency to leave it (Johnstone, '08), coupled with their ability to detect and follow slight differences in water is a sufficient explanation of all their peculiar migrations. The close way in which animals stay about certain localities from generation to generation is hardly appreciated. Thus as Johnstone points out, the herring of the east coast of Britain are largely local, having formerly been assumed to belong to shoals that came from distant points.

The experimental method cannot of course determine the cause for the absence of fishes from any given point but must be accompanied by hydrographic studies. Such combined efforts must give very trustworthy results; hydrographic studies alone may lead to entirely erroneous assumptions because of the lack of knowledge of the sensibilities of the fishes concerned and the selection of some insignificant factor correlated with their absence or presence, as an explanation. Such correlates, offered as explanations, become the basis of erroneous remedial measures.

Noting the remarkable discriminations of fishes for differences in alkalinity, acidity and neutrality, a note of warning may be sounded in regard to the relation of pollution to the run of her-

ring, and the presence in valuable numbers of many other fishes. Their tendency to avoid acid waters, hydrogen sulfide, etc., which result from decomposition and are increased by the presence of refuse of fish canneries, sewage, etc., makes diversion of such refuse from the sea an important consideration. The Baltic towns of the Hanseatic League were dependent in part upon the herring industry and after a century of great growth and prosperity fell into decline at the middle of the fourteenth century. Their prosperity was the accompaniment of the presence of great shoals of herring off the Island of Rügen in the Baltic. Their decline was caused in part by the failure of the herring industry and the supposed migration of the herring to the North Sea which has since been the center of the industry. Schouwen (on the Netherland coast of the North sea) appears in the fourteenth century to have been frequented by the herring shoals in preference to Rügen (Yeats, '86). The rapid growth of the Netherland cities, their supremacy and final separation from the Hanseatic league followed. A little later the herring again changed their haunts choosing the coast of Norway where both Norsemen and Netherlanders caught them. The Beukelszoon method of curing herring having come into use nearness to home was no longer a necessity. The Norse fisheries flourished until 1587 when an "apparation of a gigantic herring frightened the shoals away." Thus it appears that the development of the herring industry in each locality led to the apparent desertion of the locality by the fish, though the migrations assumed by historians may be doubted (Yeats) (Putzger '01, p. 17a). Was this due to the contamination of the sea by the cities, or merely to over catch? Whichever may have been the case it is certain that contamination will not invite runs of the herring. The common assumption that the sea is so large that pollution cannot have a significant rôle is rendered entirely untenable by the greatly increased sensitiveness of the marine fishes as compared with fresh water ones.

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